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THE USE OF THE FALLOUT METEOROLOGICAL MESSAGE FOR HIGH ALTITUDE BALLISTIC TRAJECTORIES

JUNE 1982

T. J. Bander
W. E. Davis

Battelle
Pacific Northwest Laboratories
Richland, WA 99352

Under Contract Number DAAG29-76-D-0100

CONTRACT MONITOR: Stephen L. Cohn

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US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

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As projectiles of new weapons systems traverse altitude ranges of 20 to 30 km, where no meteorological information exists for ballistics, meteorological information is necessary in this range to assist in targeting the weapon. An algorithm has been developed and tested using the information available about the windspeed and direction from the fallout meteorological message as input into the ballistic equations. As a result of using this information, the comparisons with the current default techniques shows an increased accuracy

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≥ 25 percent. When climatological values of temperature and density are used with the winds from the fallout meteorological message, an increased accuracy of ≥ 30 percent over default is obtained. Another technique using extrapolation of meteorological data with the fallout met message winds realized a 90 percent improvement over default.

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SUMMARY

The United States Army Field Artillery School needs to know the expected meteorological impact displacements for new weapons traversing the 20 to 30 km altitude range. At present the ballistic information uses the standard atmosphere for temperature and density above 20 km with zero windspeed. With the incorporation of the windspeed and direction from the fallout meteorological message, an increase $\geq$ 25 percent in accuracy over default can be expected. This technique has been tested using five years of data from Berlin yielding a comparison with default for seasonal and annual values of mean miss values. To implement the fallout met message technique for field use requires only a computer software change. When the climatological values of temperature and density are included, an increased accuracy of $\geq$ 30 percent occurred. To implement this last technique for field use would require both procedural as well as software changes.

Two other techniques were tested which reduced the displacement errors $\geq$ 85 percent and $\geq$ 90 percent, respectively. These techniques would require both procedural and computer software changes in order for them to be used in the field.

ACKNOWLEDGMENTS

We would like to thank Mr. Stephen Cohn for his valuable suggestions. Also we extend our thanks to Roger Schreck for his efforts in running the computer programs and his work done on the graphics.

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INTRODUCTION

With advanced technology in artillery ballistics, projectile delivery at ranges greater than 50km can be expected. Under certain conditions these projectiles will traverse altitudes from 20km to 30km above ground level (AGL). The expected meteorological effects above 20km on the target displacement error needs to be investigated because the current computer meteorological message provides information only to 20km AGL. This report presents preliminary results of a comparison of three techniques which extend the maximum ordinate of the artillery meteorological message for application to projectiles traversing altitudes from 20 to 23km AGL.

This report is an extension of work done by Blanco (1981)[1] which showed significant improvement for two of his techniques over the default technique. The default technique uses the standard atmosphere for temperature and density with zero winds. The first technique of Blanco consisted of extrapolating the temperature and density with height and assumed constant wind using data from 20km AGL. For extrapolations up to 3km above 20km AGL, the extrapolated values significantly reduced errors in estimating meteorological effects on misses. His second technique utilized climatological values of temperature and density. The data above 20km was estimated using these climatological values with the observed temperature, density and wind at 20km. His second technique was better than the default method but less effective than the extrapolation method. An error reduction of 64% using the extrapolation technique and a 53% reduction using the climatological approach was realized. The present work investigates the use of wind speed and direction from the fallout meteorological message and determines the reduction in error of the misses.

The new techniques were compared against the default method of using standard atmosphere temperature and density above 20km. One of the constraints on the investigation was that the new techniques be applicable to field conditions. Using the winds from the fallout meteorological (met) message,[2] the new techniques were compared to the default method. The reason the fallout met message was chosen for use is that it is available to the field sites and

could be incorporated with a minimum of change in current operational procedures. Also included for comparison is the extrapolation technique developed by Blanco (1981).

Fallout Met Message

An example of a fallout met message is shown in Figure 1. For this study the zones of interest (10-15) in the message cover the altitude range of 20-30km. This message is available every 6 hours in the field. The method used to incorporate the fallout met message in the ballistic computation is as follows. A five year data set from Berlin consisting of upper air soundings of temperature, pressure, dew point depression and winds was selected to form the data base. The data was processed and the winds vector averaged to fo· a fallout met message. These winds were then used in the different techniqu The original Berlin data was assumed to yield the actual meteorology affec the trajectory, i.e., the target displacement error was zero using this da The following section relates how the fallout message winds are utilized in the different techniques and how they are used in computing target displacement errors.

FALLOUT MET MESSAGE

For use of this form, see FM 6-15; the proponent agency is United States Continental Army Command.

IDENTIFICATION	OCTANT	LOCATION		DATE	TIME (GMT)	DURATION (HOURS)	STATION WEIGHT (10'S M)
METFM	Q	$L_aL_aL_a$ or xxx	$L_oL_oL_o$ or xxx	YY	G G G	G	hhh
METFM	9	WALNUT		17	180	4	036

ZONE HEIGHT (METERS)	LINE NUMBER ZZ	TRUE WIND DIRECTION (10'S MILS) ddd	TRUE WIND SPEED (KNOTS) FFF	ZONE HEIGHT (METERS)	LINE NUMBER ZZ	TRUE WIND DIRECTION (10'S MILS) ddd	TRUE WIND SPEED (KNOTS) FFF
SURFACE	00	310	004	16000	08	635	018
2000	01	366	008	18000	09	035	024
4000	02	513	013	20000	10	132	025
6000	03	572	016	22000	11	274	022
8000	04	601	010	24000	12	135	042
10000	05	377	013	26000	13	169	027
12000	06	379	021	28000	14	150	033
14000	07	411	017	30000	15	169	039

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FIGURE 1. An Example of the Fallout Met Message

METEOROLOGICAL APPLICATION OF THE TECHNIQUES

Available techniques for extending and incorporating the meteorological data for projectiles reaching higher than 20km AGL can utilize computer hardware and software or a combination of both. In this report only software techniques will be discussed. The Berlin radiosonde data are assumed to represent the actual atmospheric parameters. The comparison of the new techniques with the Berlin radiosonde data reduces to how well the actual meteorological profile can be estimated by the new techniques using the fallout met message. This assumes that when the measured meteorological data are used for aiming an artillery piece, the displacement due to meteorology on the target is zero.

The first technique examined--one which the Artillery currently uses--will be called the default method. Whenever a meteorological message or climatological table is unavailable, the artillery pieces are aimed by using a meteorological message which contains standard temperature and density data. The standard wind is taken as zero speed for all layers. In cases where the meteorological messages are unavailable or are not complete to the 20km AGL limit, the current procedure defaults to these standard meteorological conditions for the missing data.

The second technique uses the winds from the fallout met message. Presently ballistic messages are available to 20km altitude at 2 hour intervals. However, the fallout met message is available to 30km altitude at 6 hour intervals. Winds from the fallout met message were incorporated for the 20-30km layer. Using these winds and default standard atmosphere temperature and density a comparison was made to the default technique.

The third technique is an extension of the second technique whereby a climatology (seasonal and annual) of temperature and density are used in combination with the fallout met message winds as input to a ballistic message.

A fourth technique developed by Blanco (1981)[1] utilizes an extrapolation method. This method uses extrapolated values of wind, temperature and density in place of missing data. The last available layer of data is used to

estimate the remainder of the meteorological message. The constant wind direction and speed at the 20km layer is used for the higher layers. The extended values for temperature are computed by using the gradient of the standard atmosphere temperature. The hydrostatic extrapolation of the density is computed by using the extrapolated temperature values and the density value at 20km. The detailed extrapolation, assuming the hydrostatic equation and the perfect gas law, yields the following expressions:

Gravity	$g_o = 9.80665 \text{ m s}^{-2}$
Air molecular weight	$M = 28.966 \text{ g mol}^{-1}$
Gas constant	$R = 8314.32 \text{ J } (°K)^{-1} \text{ mol}^{-1}$
Geopotential layer	$\Delta H(I) = \left(\frac{9.7376}{g_o}\right) (I)(1000)\text{m}$ where $I = 1, 2, 3$
Extended temperature	$T(I) = T_o + T_s(I) - T_{s_o}$ where T_o = 20km value (°C) T_s = standard temperature T_{s_o} = standard temperature at 20km
Lapse rate	$L(I) = [T(I) - T_o]/\Delta H(I)$ L is in (°K) km^{-1}
Extended density	$\rho(I) = \rho_o \left[\frac{[T_o + 273.16]}{[T(I) + 273.16]}\right]^{\left(1 + \frac{g_o M}{RL}\right)}$ where ρ_o = 20km value and ρ is in g/m^3

The extrapolated values for layers of 1km thickness are obtained by incrementing the above relationships with respect to I until the maximum altitude desired is reached.

The fifth technique developed utilizes the same extrapolation for temperature and density as in the fourth technique. The fallout met message winds were used instead of constant winds.

BALLISTIC SIMULATION

The method used to compare the five techniques is that of ballistic weighting. This method was incorporated into a computer algorithm which is used to compute a distance displacement from the default method. By averaging impact and displacements and computing the standard deviation of the different techniques, a comparison was made to determine how each technique performed relative to default. The default displacements assume the United States Standard Atmosphere (USSA) conditions (1962).

The displacement is calculated for the averaged parameter (wind, temperature, or density) $\overline{P}(Z)$ for each 1km layer from 23 through 26km (20 to 23km AGL). In the ballistic simulation, each parameter (normalized by USSA) is multiplied by the weighted response function [$\delta w'(Z)$]. This function contains the ballistic characteristics of the weapon system. The required ballistic information are the weighting factors and the unit effect of the meteorological parameters for each of the 1km layers of the extended altitudes. The sum of these effects through the maximum altitude of the proposed trajectory yields the effective displacement (D) from the standard conditions. Knowing this displacement, an artilleryman can compensate for the meteorological deviations from the standard by adjusting his weapon aim and firing for effect. The displacement for each parameter is formulated as follows:

$$D = \int_{z_0}^{z} \delta w'(Z) \left[\frac{\overline{P}(Z) - \overline{P}_s(Z)}{\overline{P}_s(Z)} \right] dZ \quad , \qquad (1)$$

where δ = unit effect; $w'(Z)$ = ballastic weighting; dZ is the increment of height; and the parameter $\overline{P}(Z)$ is temperature, density or wind. In the case of wind there is no standard, and the $\overline{P}(Z)$ is not normalized.

When summed over a data set, equation 1 will yield a set of impact displacements describing the dispersion of the analyzed weapon system. This dispersion is mathematically represented with a bias and a variance for each component (cross and range) about the target. The conventional artillery

practice is to describe the dispersion of a weapon in terms of a circular error probable (CEP).[3] This criterion is defined as the circular radius of the smallest circle about the target that contains one-half of the total impact displacements. This procedure is used by the U.S. artillery even though the actual dispersion of a gun is elliptical. Therefore, in demonstrating the differences between the extending techniques, this report uses elliptical probable error rather than the CEP. There are cases when a small dispersion is based too far from the target, thereby yielding artillery fire ineffective. One is cautioned that when converting to CEP about the target, the comparison of results will produce a different interpretation of the evaluated meteorological messages. The bias due to meteorological parameters is a major contributor to the impact displacement. In practice, through observed fire the Fire Direction Center would correct for this bias, which is caused from the unavailability of a meteorological message update or lack of a procedure to estimate data above 20km AGL.

The results show that the dispersion is a function of the atmospheric condition. Wind, temperature, and density affect the range impact displacement, while only wind affects the cross component.[2] Since the azimuth of fire (θ_i) determines the wind bias, calculation of a mathematical composite for eight azimuths was considered to be more appropriate. The weapon system was therefore launched at targets on a circle at increments of 45 degrees. The impact displacements are summed and give the composite dispersion plotted in Figures 2-7. The range and cross bias due to the wind are cancelled in the composite dispersion. The temperature and density bias are not cancelled because of the nature of the ballistic computation. If the sample contained data with temperature and density above and below the standard, then the bias would be affected in the composite. The next section will present results for the Berlin radiosonde data collected from 1971 to 1975.

For each rocketsonde flight, equation (1) is applied to the cross (D_C) and range (D_R) components as follows:

$$D_{C_i}\ (\theta_j,\ Z) = \delta_C \sum_{Z_o}^{Z} w'_C(Z)\overline{W}_{C_i}\ (\theta_j,\ Z)\ ; \qquad (2)$$

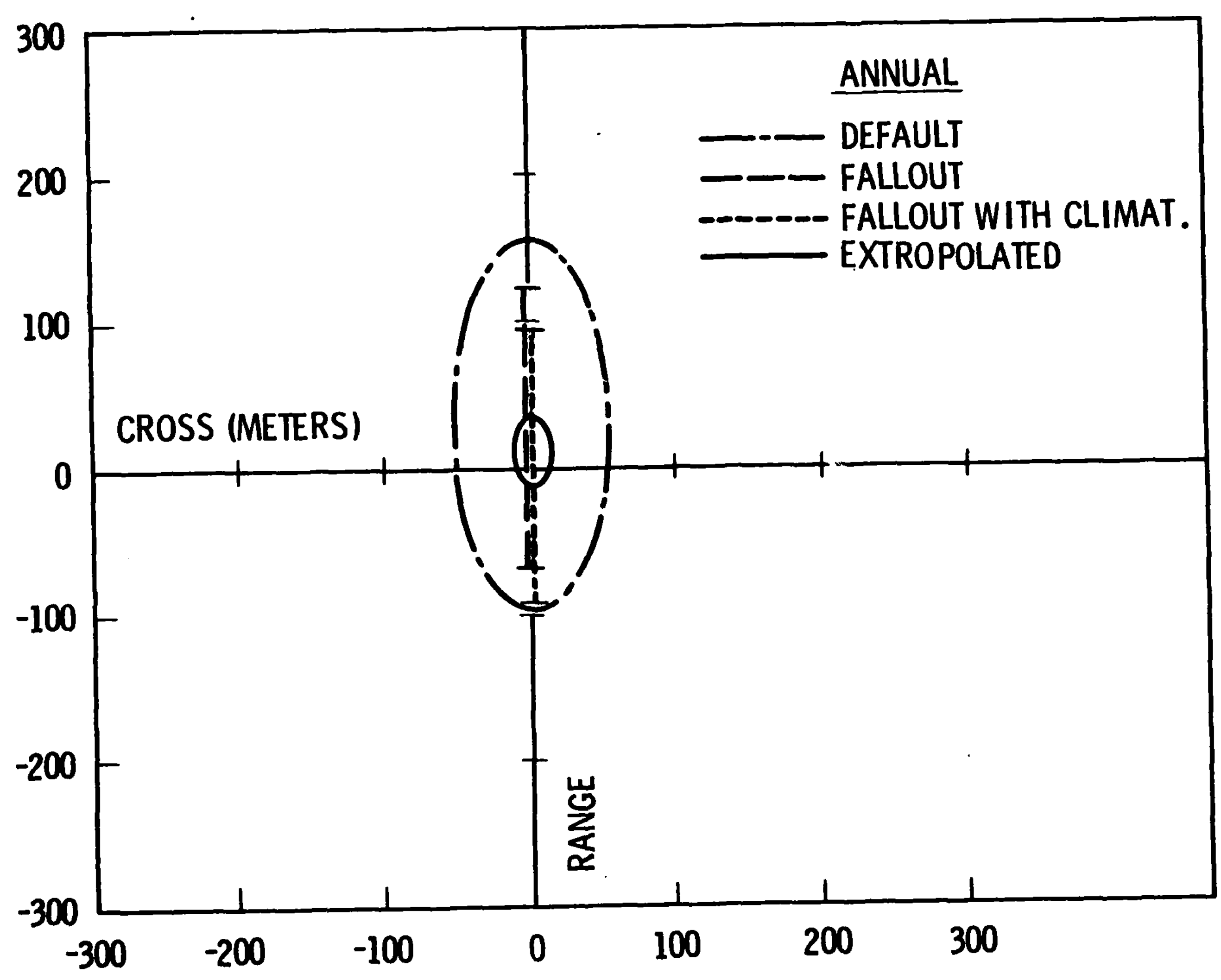

Figure 2. Elliptical Probable Error Plot for the Annual Displacement Errors.

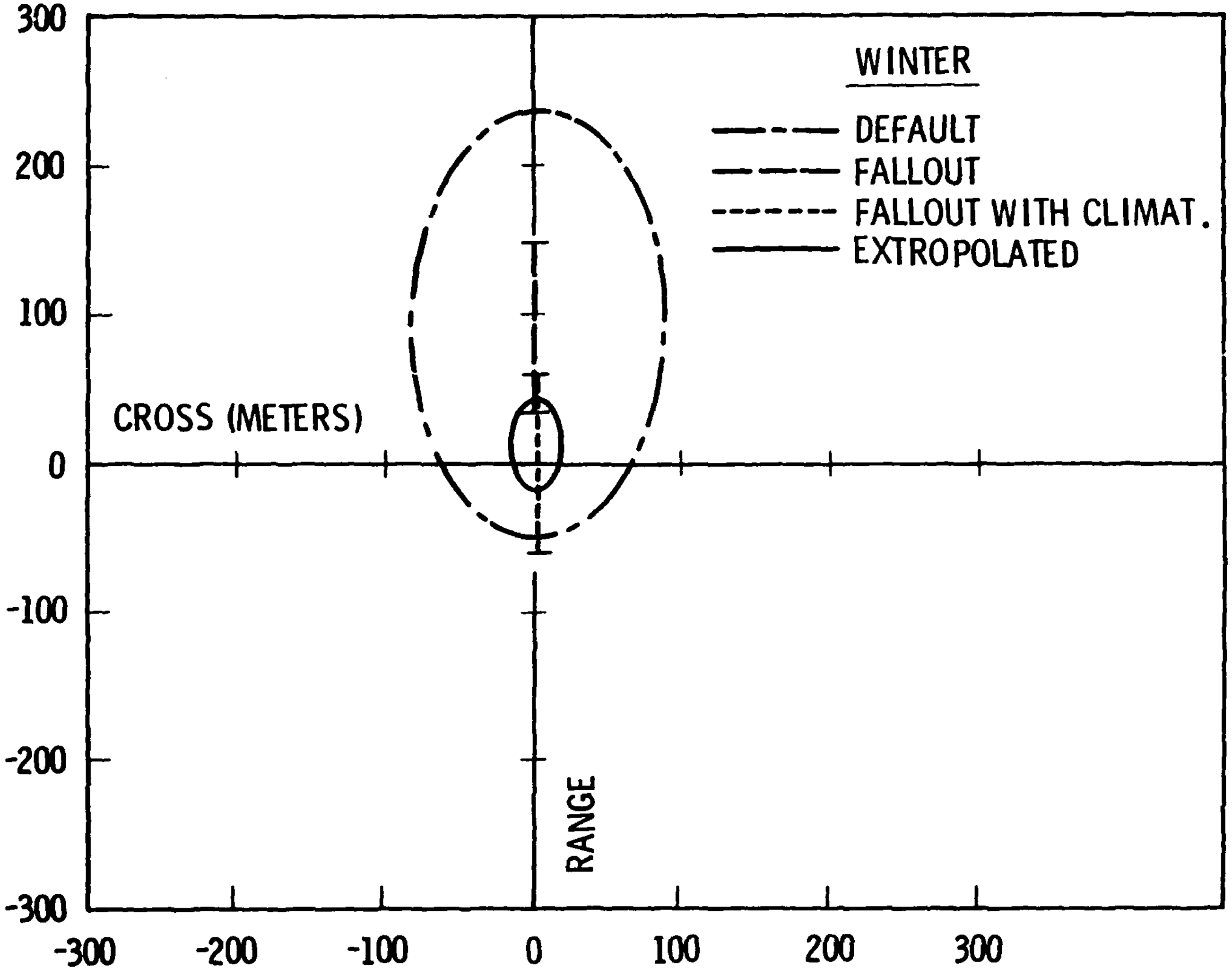

Figure 3. Elliptical Probable Error Plot for the Winter Displacement Errors.

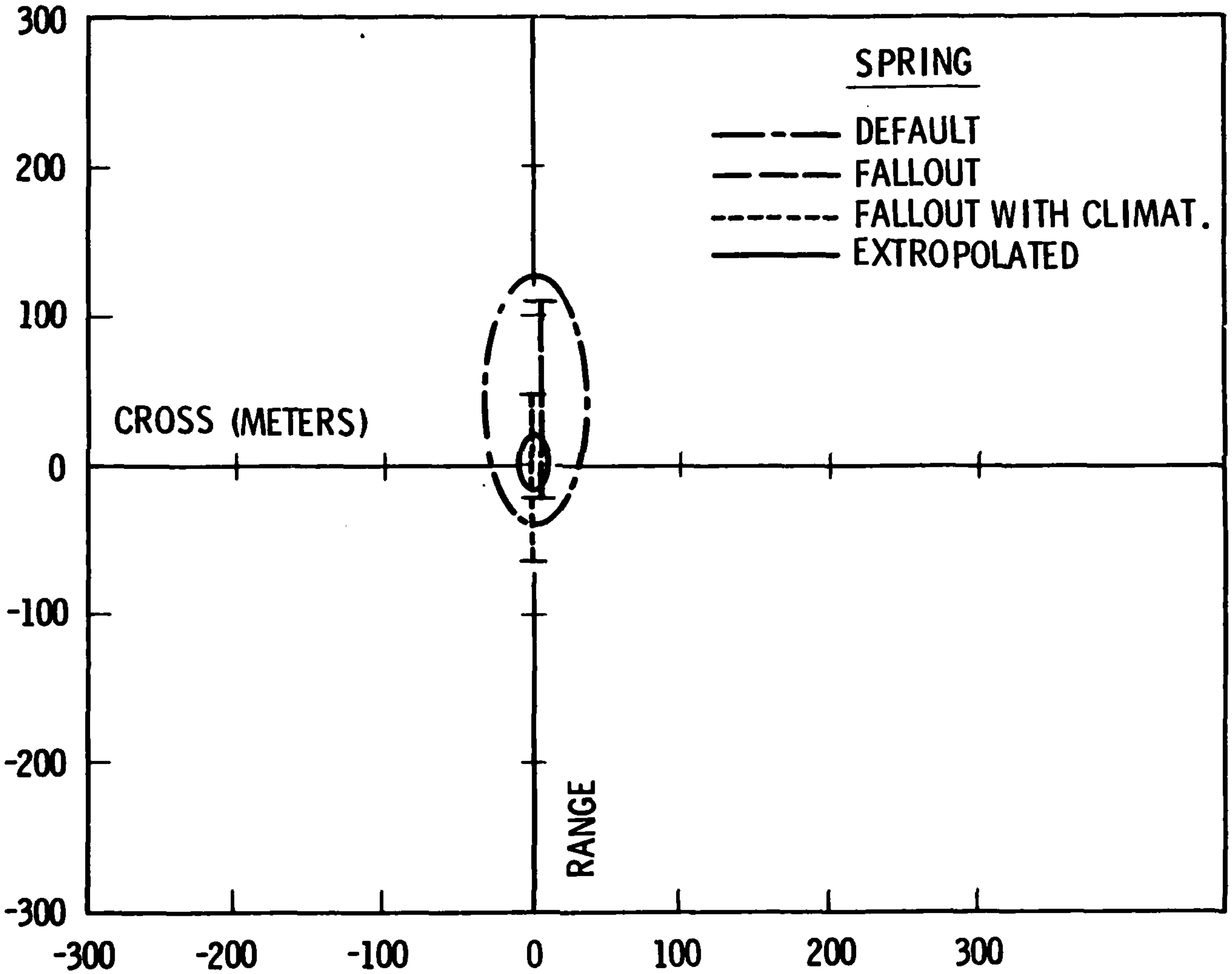

Figure 4. Elliptical Probable Error Plot for the Spring Displacement Errors.

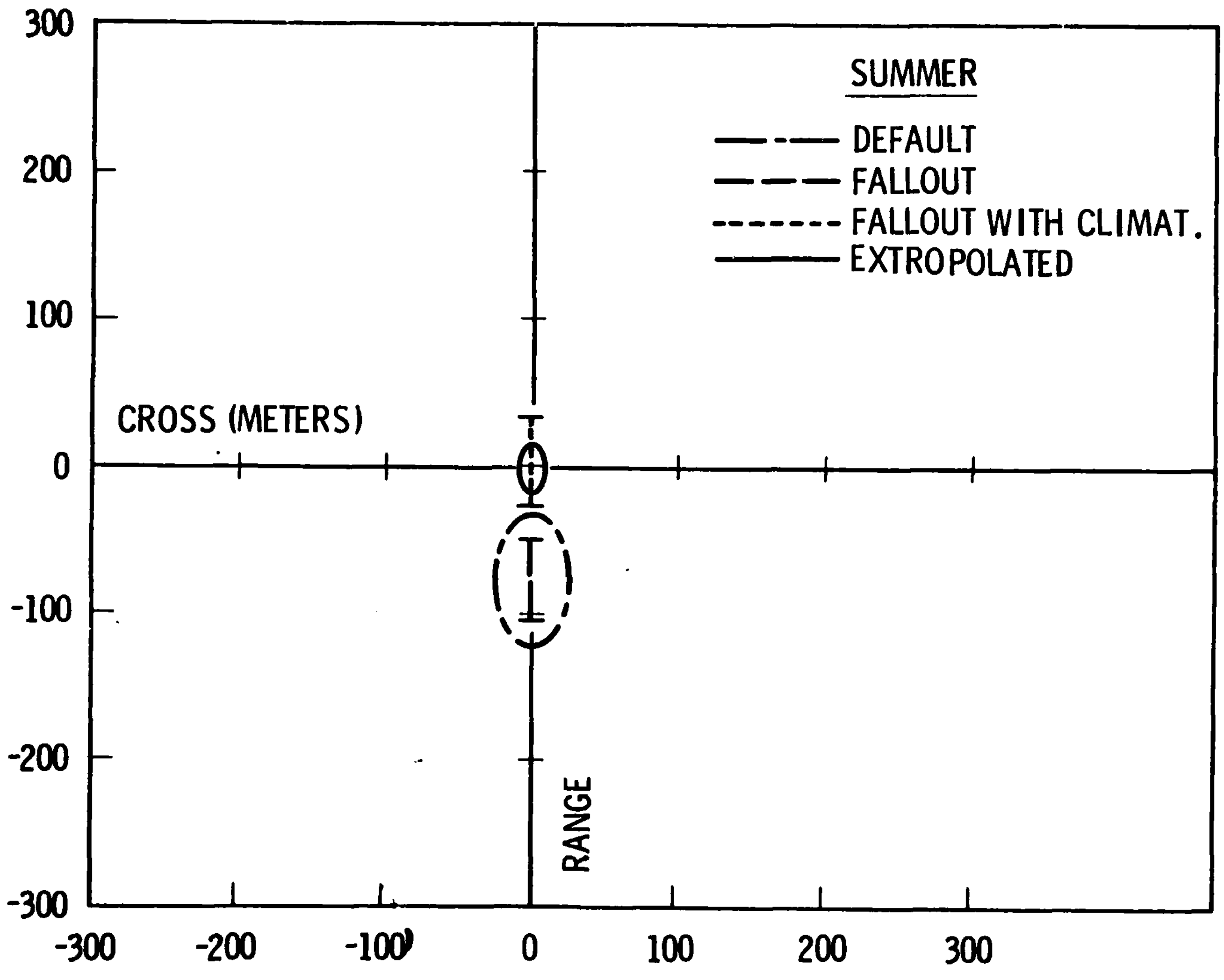

Figure 5. Elliptical Probable Error Plot for the Summer Displacement Errors.

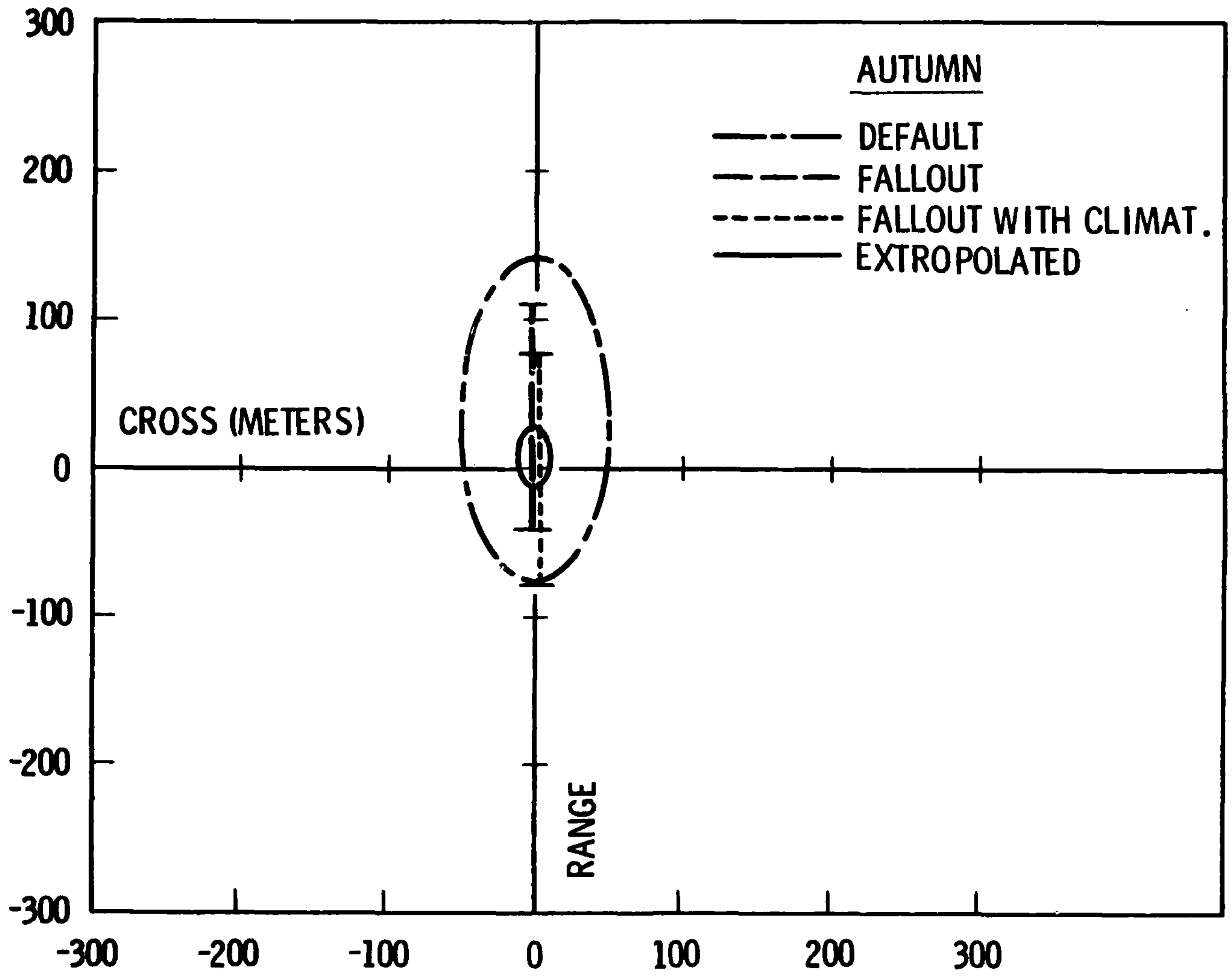

Figure 6. Elliptical Probable Error Plot for the Autumn Displacement Errors.

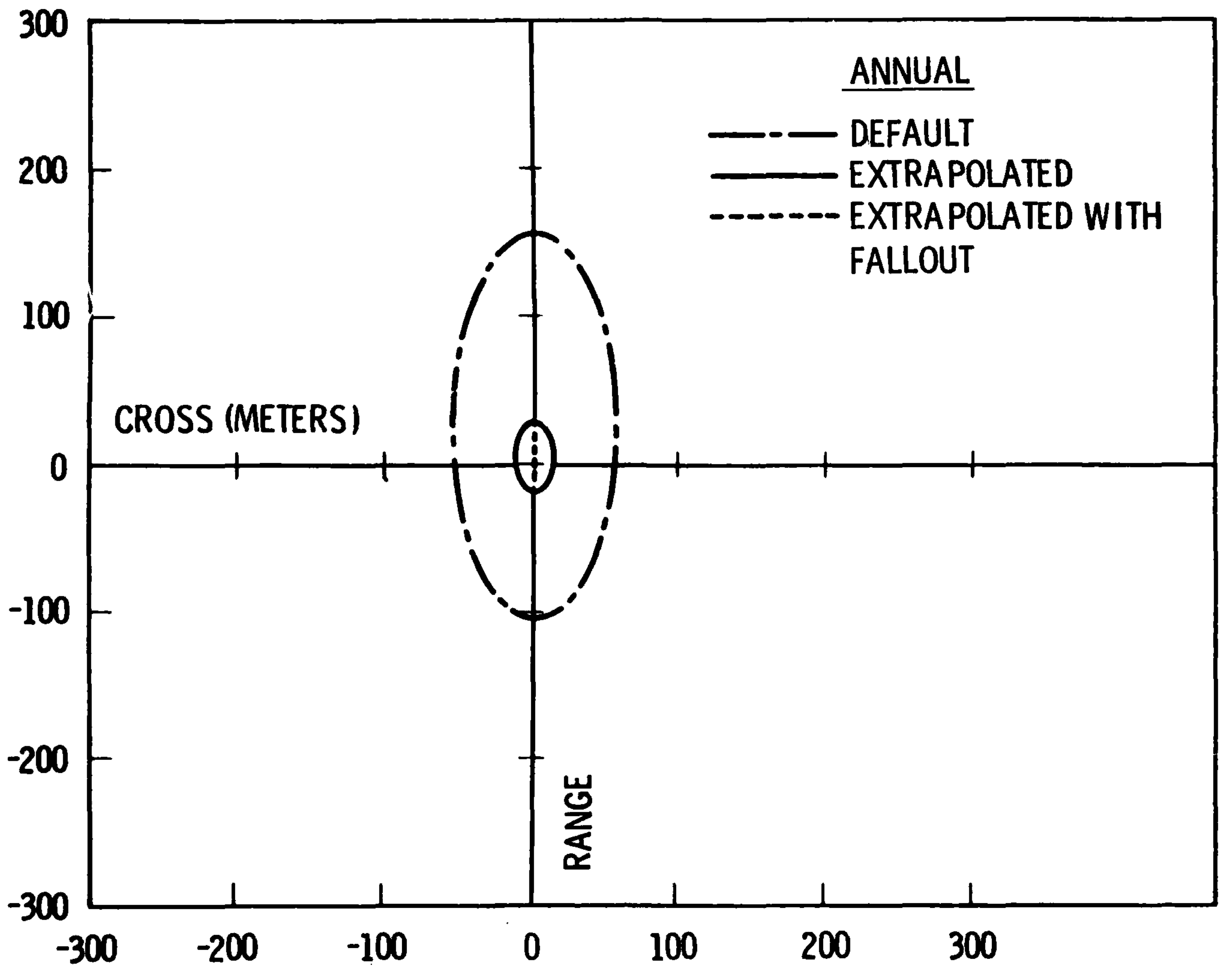

Figure 7. Elliptical Probable Error Plot for the Annual Displacement Errors

$$D_{R_i}(\theta_j, Z) = \delta_R \sum_{Z_o}^{Z} w'_R(Z)\overline{W}_{R_i}(\theta_j, Z) + \delta_T \sum_{Z_o}^{Z} w'_T(Z)\,\frac{\Delta T_i}{T_S} + \quad (3)$$

$$+ \delta_\rho \sum_{Z_o}^{Z} w'_\rho(Z)\,\frac{\Delta \rho_i}{\rho_S} .$$

The cross component does not contain the temperature (T) and density (ρ) effects. The displacement statistics for the error due to the unextended meteorological message are computed as follows:

$$\text{Bias} = \sum_{i}^{n} \sum_{j}^{8} D_i(\theta_j, Z)/8n \quad ; \qquad (4)$$

$$\text{Variance} = \frac{8n \sum_{i}^{n} \sum_{j}^{8} D_i(\theta_j, Z)^2 - \left(\sum_{i}^{n} \sum_{j}^{8} D_i(\theta_j, Z)\right)^2}{8n\,(8n - 1)} . \qquad (5)$$

Generalizing the results, consider that for each radiosonde (i) there are eight azimuths (j) providing a total of 8n impact displacements for each month, where n is the number of soundings.

Technique Comparison

Radiosonde data from Berlin, Germany (1971 to 1975) were used to compute the meteorological displacements of a high altitude projectile. Computations were made using equation 1, which represents the displacement from the default method. The lower altitude portion of the data were not used in the calculations and assumed to input no error since the objective was to evaluate the effect of the 20-23km AGL layer. Only the meteorological effects for this layer are shown in Table 1.

Table 1 presents the rms miss based on five years of Berlin data. The data is broken into 5 sets with 4 sets being the miss by season of the year and the fifth set is the annual.

TABLE 1

COMPARISON OF RMS MISS (METERS)

$$\left(\overline{m^2} + \sigma^2_{\bar{m}}\right)^{1/2}$$

	Winter	Spring	Summer	Fall	Annual*
Sample size	432	448	424	458	1762
Radiosonde	---------------	actual	impact	------------	
Technique					
1. Default standard	177	92	93	110	123
2. Fallout	112	74	84	77	88
3. Fallout with climatology	51	57	26	68	83
4. Blanco's extrapolation	35	19	15	22	24
5. Extrapolation with fallout	19	13	9	14	14

*Annual averages of temperature and density used.

Discussion of Results

As can be seen in Table 1, the smallest rms miss was obtained using the fifth extrapolation technique. The next smallest was the fourth technique, Blanco's extrapolation. The third technique was next using the fallout met message winds with climatology, and the least improvement over default was from the use of fallout met message winds with default standard atmosphere temperature and density. Figures 2 through 7 show the elliptical probable error plots. As can be seen the advantage of the use of the fallout met message winds is the almost complete removal of cross wind bias errors. The other point not shown in these plots is the removal of error due to the winds for the range. This is because the fallout met message winds are essentially equal to the observed winds. What is left is the temperature and density errors by using standard atmosphere in the fallout met message technique. When the climatology is introduced for temperature and density on a seasonal or annual basis, the reduction in error can be seen in Table 1. On the annual basis the error reduction is not as large because the annual climatological values are near standard atmosphere values.

Blanco's technique gives good results because the extrapolation of temperature and density based on observed values at 20km AGL for each radiosonde release was a reasonable estimator of data at the higher levels. Unpublished data* shows that this technique seriously deteriorates when extended beyond 3km. Combining Blanco's extrapolation of temperature and density with the winds from the fallout met message gives the best results with an error reduction of 90% for the annual case.

Table 2 indicates the changes required in order to implement the techniques. Default standard is presently being used. The use of the winds from the fallout met message would require that the winds be entered into a computer program, which would yield the effects on the projectile and allow changes to be made on range and azimuth settings. This would require only a software change.

The use of the two extrapolation techniques, Blanco's extrapolation and extrapolation with fallout, will require procedural changes so that temperature and density can be input at the 20km level. In addition, the winds from

*unpublished data, Blanco, 1982.

TABLE 2

FIELD APPLICABILITY OF TECHNIQUE

Technique	Status	Change Necessary
1. Default standard	In use	none
2. Fallout	Developed	computer software change
3. Fallout with Climatology	Developed	procedure and computer software change
4. Blanco's extrapolation	Developed	procedure and computer software change
5. Extrapolation with fallout	Developed	procedure and computer software change

the fallout met message would have to be entered into a computer program (software change).

The application of these techniques should be possible on a global basis. Results from Blanco (1981) using White Sands data along with those using the Berlin data indicate that even for widely separated sites significant reduction in displacement errors can be realized. However, the magnitude of displacement errors will depend on the variability of the temperature density and winds at a particular site.

Recommendations and Conclusions

The use of the fallout met message winds reduces the displacement errors compared to the default technique which uses standard atmosphere temperature and density with no winds for 20-23km AGL. When the annual climatological values of temperature and density for five years of Berlin data were used with the fallout met message winds, a reduction of $\geq$30% in the displacement errors occurred. When applied on a seasonal basis, displacement error reductions of as much as 70% occurred. Both of these techniques using the fallout met message winds can be applied in a field situation. The first could be applied with a computer software change. The second would require the utilization of a climatological base as well as a computer software change.

The extrapolation technique developed by Blanco (1981) yielded good results both on a seasonal and annual basis with $\geq$85% reduction in displacement errors. However, based on unpublished data this technique deteriorates seriously when extended beyond 3km.

The best technique combined the fallout met message winds with the temperature and density extrapolations by Blanco (1981). Based on results in this paper a 90% reduction in displacement errors occurred.

A recommendation is made that time and space correlations be made to determine the degradation of results from observation time and with distance from observation site.

A second recommendation is that these techniques be applied over the vertical range of 20-30km AGL in order to fully test Blanco's 1981 results.

Finally, since seasonal climatology has aided in reducing displacement errors, seasonal values should be used rather than annual values for density and temperature.

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